VASCULAR INJURY

Original Release/Approval		18 Dec 2004	Note: This CPG requires an annual review.	
Reviewed:	Nov 2008	Approved:	7 Nov 2008	
Supersedes:	JTTS Clinical Practice Guidelines for Vascular Surgery, updated Apr 2008			

1. Goal. To provide guidance on the treatment and surgical management of vascular injuries sustained by combat casualties.

2. Background. The treatment of vascular injuries in combat casualties can be a challenging endeavor in a resource limited environment and requires not only technical expertise on the part of the operating surgeon, but solid judgment on when to perform temporizing maneuvers, vice definitive repairs.

Surgeon's at all Level II and III facilities need to be intimately familiar with the use of vascular shuts as a means to stabilize a critically wounded casualty and then move them along the continuum of care.

3. Evaluation and Treatment. See Appendices A and B for general principles and a decision algorithm. The recommendations below are divided into specific anatomic areas of concern.

a. Neck Vasculature. If at all possible, attempt to get a baseline neurologic exam on your patient. This is one of the best predictors of outcomes in carotid trauma.

1) Zone III (cephalad to the hyoid bone). Arteriography or CT angio will help to define if there is a significant vascular injury.

a) Without access to angiography and/or CT the wound can be packed and the patient rapidly MedEvac'd.

2) Zone II (between the hyoid bone and the sternal notch). Injuries to this zone must be explored. A standard neck incision is made from the mastoid to the sternal notch on the anterior border of the sternocleidomastoid muscle. Identify the facial vein and divide it, as this marks the bifurcation of the carotid artery. Retract the internal jugular posteriorly using a self retaining retractor. After repairing vascular injuries in this zone, one must have a high index of suspicion and assess for esophageal and tracheal injuries.

a) Internal Jugular Vein (IJV). Injuries to the IJV can be repaired with lateral venorraphy or ligated.

b) Common Carotid Artery (CCA). Obtain proximal control outside of the hematoma at the base of the neck using a Rummel tourniquet on the CCA while being careful not to ensnare the vagus nerve. If possible obtain distal CCA control proximal to the CCA bifurcation; with this technique no shunt is required. The injury may be repaired using lateral arteriography, patch angioplasty, end-to-end anastomosis or bypass. If the patient is in extremis, the CCA may be ligated with a low incidence of stroke due to the perfusion of the ICA from an intact ECA.

c) External Carotid Artery (ECA). Injuries to the ECA may be repaired using standard techniques or ligated since this is usually well tolerated.

d) Internal Carotid Artery (ICA). Injuries to the ICA should be repaired if at all possible. While ligation is possible, the incidence of stroke is considerable. If there is poor inflow from the injured carotid, carefully pass a #3 Fogarty balloon embolectomy catheter, no more than 2-3cm past the bifurcation, to retrieve any thrombus. If there is still no inflow from the ICA, ligation may be the best answer. (However, this is a controversial point.) ICA injuries with segmental loss may be repaired using RGSV interposition graft or ECA transposition.

(1) If the injury is to the high internal carotid artery, exposure is facilitated by nasotracheal intubation, division of the omohyoid muscle, the descendans hypoglossal nerve or mandibular subluxation. In the case of a distal carotid injury that is too high for reconstruction, then ligation is appropriate.

(2) In the case of a distal ICA lesion that you cannot get distal control on at all, then insert a # 3 Fogarty embolectomy catheter into the distal end of the ICA; place 2 clips just below the balloon to keep it expanded and cut the shunt to leave the balloon in the ICA to tamponade it.

e) Vertebral Artery (VA). Use bone wax to plug a bleeding VA from the vertebral canal. Additionally, a Foley catheter may be used to tamponade the bleeding from a VA until the patient can be MedEvac'd.

For all injuries in this zone, airway protection, packing and rapid evacuation are options, particularly for the far forward surgical units with limited resources.

3) Zone I - Supra-Aortic Trunk Vascular Injuries.

a) General Principles. Dissection into mediastinal hematomas can be disorienting. Often it is useful to open the pericardium and trace vessels upward. Divide the left Innominate vein to find the Innominate artery and continue cephalad. BE CAREFUL not to injure the phrenic nerve as it courses behind the right subclavian vein and in front of the anterior scalene muscle and right subclavian artery. When dissecting the left carotid artery in this plane BE CAREFUL not to injure the left vagus nerve as it descends in front of the aortic arch and gives off the left recurrent laryngeal nerve. DO NOT plunge into a stable mediastinal hematoma for blunt trauma; this is often an avulsion of the Innominate artery. The best management method for injuries to thoracic outlet arteries is usually bypassed using a synthetic conduit such as Dacron.

Ligation of supra-aortic trunk arteries can be performed, but may come at the cost of stroke.

b) Left subclavian artery. Gain proximal control through a high left anterolateral thoracotomy in the 3rd intercostals space (above the nipple). Once proximal control obtained, expose the injured subclavian through a supraclavicular incision for repair (avoid injury to phrenic nerve, recurrent laryngeal nerve and thoracic duct if possible.)

c) Right subclavian artery. Gain proximal control through a median sternotomy. Repair through right supraclavicular incision.

d) Subclavian veins. May ligate if needed; however, expect arm swelling, and consider elevation, and rarely fasciotomy. May repair using standard techniques primary, lateral venorraphy, interposition graft. Use infraclavicular incision for exposure.

e) Innominate artery. Repair or bypass through a median sternotomy.

f) Innominate Veins. May ligate if needed; however, expect arm swelling, and consider elevation and rarely fasciotomy. Ligation and division of left Innominate vein useful to expose arch vessel injuries. May repair using standard techniques primary, lateral venorraphy, interposition graft.

(1) Ligate or repair through median sternotomy, emergent bypass probably not necessary unless both veins injured.

If both Innominate veins are injured, the patient may experience severe SVC syndrome with facial and upper airway edema.

g) Left common carotid artery. Repair or bypass through a median sternotomy.

h) Azygous Vein. Often difficult to recognize. Usually encountered when performing an exploratory right thoracotomy for hemothorax. When recognized, clamp, ligate, or suture ligate. Look for associated esophageal or bronchial injuries.

b. Upper Extremity Vascular Injuries.

1) Axillary Artery. Exposed through an infraclavicular incision - midclavical to deltopectoral groove through the clavipectoral fascia. Options include shunt, ligation and fasciotomies, repair or bypass.

2) Axillary Vein. May ligate if needed; however, expect arm swelling, consider elevation, and rarely fasciotomy. May repair using standard techniques primary, lateral venorraphy, interposition graft.

3) Brachial artery. **The most frequently injured artery in the body**. Gain access by cutting down on medial aspect of upper arm between biceps and triceps; may extend proximally or distally as needed. Avoid injury to basilic vein and median nerve. S-incision if there is need to cross antecubital fossa. If injury is below Profunda brachii, patient may tolerate ligation. Other options include lateral repair, patch angioplasty, end-to-end anastomosis, or interposition graft. Ensure adequate muscle coverage of artery or vascular repair.

4) Radial/Ulnar artery. First assess Doppler flow in hand; if ulnar intact with Doppler flow, simple ligation is probably the best and most expedient. Ligation, lateral suture, patch, EEA or interposition graft all possible.

c. Abdominal Vascular Injuries. Explore all retroperitoneal hematomas and perinephric ones, selectively.

1) Aorta. **Try to get away with lateral repair in suprarenal aortic injuries.** Clamping the aorta at this level for extended period of time during repair will result in visceral ischemia and coagulopathy. Beware of iatrogenic vein injury in an inframesocolic hematoma.

a) For infrarenal aortic injuries, attempt lateral repair, if possible. If not feasible, an interposition tube graft may be a better option than patch angioplasty.

2) Inferior Vena Cava (IVC)

a) Juxtarenal IVC. Associated with a hematoma above the duodenal loop. **If not expanding, DO NOT EXPLORE.** Expose the IVC through Kocher or Catell-Braasch maneuver. Insert a retractor over inferior surface of liver and tow in to give exposure and compress suprarenal IVC. Mobilize the right kidney and divide the left renal vein to improve exposure to this portion of the cava. Do your best to perform lateral repair of suprarenal IVC. Damage control options include packing or ligation.

b) Infrarenal IVC. Associated with central hematoma that is inframesocolic. Expose through Catell-Braasch maneuver. When unroofing this hematoma, prepare for extensive bleeding, and ensure that the anesthesia team is ready for blood loss. Unroof the hematoma and compress the IVC against the spinal column, quickly position your assistants' hands to replace yours, so you can prepare to repair the caval injury. Be cautious applying clamps to the IVC; this may cause additional tearing. If the patient crashes while attempting to control the injury, compress the adjacent aorta as well Define the edges of the cava to facilitate lateral repair.

It is best not to attempt fancy repairs of the IVC in an unstable patient; if lateral repair does not work, ligate the IVC.

3) Iliac Vessels.

a) Walk the clamps distally to gradually converge on an iliac artery injury. Shunt iliac artery injury and take patient to ICU for resuscitation if the patient is too unstable to repair; and return later to fix.

(1) If unable to shunt, and patient is very unstable, ligate iliac artery and return later for femoral – femoral bypass. Don't chase a bleeder into the psoas muscle, as these may result from a bleeding ascending lumbar artery or vein which will be difficult to control if unroofed and it will respond well to simple packing. **DO NOT EXPLORE a patient with blunt trauma and a pelvic fracture unless you specifically suspect patient has a vascular injury with a pelvic hematoma).**You may need to transect the overlying right common iliac artery to expose and control an injury to the confluence of the common iliac veins. In patients with iliac vein injuries, do not attempt fancy repairs; either they respond to lateral suture or they should be ligated.

d. Peri-Hepatic Vascular Injuries. When dealing with hepatic trauma, Pringle maneuvers can be used for 30-45 minutes. If not expanding, DO NOT EXPLORE. In retrohepatic venous injuries packing is the answer. Exploration will result in the patient's death. Hepatic artery ligation may be useful in liver trauma if packing doesn't work. The supraduodenal portal vein may be ligated for damage control. **When both portal vein and hepatic artery are damaged, you must repair one of them.**

e. Mesenteric Vascular Injuries. When dealing with mesenteric vascular injuries, a second-look operation is advisable. **Blind clamping at the root of the mesentery is a recipe for**

disaster. Beware of iatrogenic renal vein injury when exploring an inframesocolic hematoma.

1) Celiac artery. Injury to the celiac access is rare but deadly. The celiac access is difficult to expose. One technique is to try a gross hemostatic stitch with a heavy suture on a big needle (0 Proline) into the lesser omentum. You may need to divide the stomach using a stapler to do get rapid exposure.

2) Superior mesenteric artery. Injuries to the proximal SMA above the pancreas are essentially aortic injuries and are best exposed through a Mattox maneuver (medial visceral rotation). Exposure through the lesser sac is another option. Usually, these injuries are associated with pancreatic and/or gastric injuries. May be best to ligate and do retrograde reconstruction. Control of the retropancreatic SMA is best achieved by dividing the pancreas. May insert shunt in SMA as a damage control maneuver. Reconstruct the SMA away from the injured pancreas, if possible. Reconstruct SMA using 6 mm ringed PTFE from distal aorta of right common iliac artery.

3) Superior mesenteric vein. You may need to divide the pancreas to repair injuries to the SMV. Repair the injured SMV if you can otherwise ligate it. The consequences of portal or SMV ligation are massive fluid sequestration, which translates into high post op fluid requirements and inability to close abdomen.

f. Renal Vascular Injuries.

1) Stable non-expanding perinephric hematomas may not need to be explored. Use judgment before embarking on repair of renal vascular injuries. Don't kill the patient attempting to salvage a damaged kidney. Try to assess the contralateral kidney when contemplating nephrectomy. Obtain proximal renovascular control before exploring expanding perinephric hematomas. On the right renovascular hilar injuries are often associated with injuries to the surgical soul (IVC, pancreas, porta hepatis). Right renovascular injuries are best exposed using a Cattell-Braasch maneuver. An injury to the right renal vein is essentially a side hole in the IVC, and therefore, saving life is more important than saving a kidney. On the left don't hesitate to ligate the renal vein. The Mattox maneuver gives you great visualization of the left kidney.

2) When performing revascularization of the kidney using bypass, perfuse the kidney intermittently using cold heparinized saline.

g. Peripheral Vascular Injuries.

1) The majority of injuries in patients with penetrating trauma can be explored directly with no need for preoperative arteriography. In patients with diffuse extremity injuries associated with vascular compromise however, arteriography is often useful if the patient is stable. It is imperative to insure that vascular repairs are covered with healthy muscle and not left exposed or bathed in devitalized infected tissue, EXPOSED GRAFTS WILL BLOW OUT. **Be liberal with fasciotomies especially in patients with popliteal artery repairs.**

2) Femoral artery. Control obtained either through standard femoral cutdown, or through oblique transplant incision above inguinal ligament. For superficial femoral arteries, repair or bypass all SFA injuries in the young, as acute occlusion in these patients is

not well tolerated. For profunda femoral arteries, repair proximal injuries or bypass, distal PFA injuries can be ligated.

3) Femoral veins. The majority of venous injuries can be ligated, especially if the patient is in extremis. If you perform venous ligation be sure to perform a liberal fasciotomy and be prepared for extremity fluid sequestration, and bleeding from venous hypertension in soft tissue wounds

   a) If the patient is stable however venous repair may help the patient avoid acute compartment syndromes or long term sequelae, especially for venous injuries above the confluence of the SFV and greater saphenous vein.

4) Popliteal Artery.

   a) Above knee. Best exposed through Hunter's canal incision, retract Sartorius muscle down and look under the Vastus medialis muscle. Use local heparin saline flush solution prior to arterial repair. Lateral arterrioraphy may be used but end to end arterial anastomosis may be possible in young patients with normal healthy arteries, in blast injuries be sure to debride an adequate amount of devitalized artery, don't cheat or you may be rewarded with a thrombosed repair If significant arterial loss use reverse greater saphenous vein interposition graft with vein harvested from contralateral extremity.

   b) Behind knee. Best exposed through medial approach, divide tendinous muscular attachments. Avoid injury to the greater saphenous vein and superficial peroneal nerve during exposure. Use deep space retractors to aid with visualization.

   c) For all popliteal artery injuries vascular shunts are a ready alternative in far forward surgical units.

5) Popliteal vein. If possible repair, as this will lead to reduced lower extremity venous hypertension and bleeding from any soft tissue defects. Often paired and can be ligated without too much sequelae.

6) Tibial arteries. First, assess distal pulses at foot, as long as there is a pulse or dopplerable signal in the foot it is not essential to revascularize other injured tibial vessels. Peroneal and posterior tibial artery injuries are best exposed through medial approach, the anterior tibial artery is most easily exposed lateral to the tibia in the anterior compartment. With proximal tibial artery injuries it is often easier to bypass to a normal tibial artery more distally than in the zone of injury. Short tibial- tibial interposition grafts with reversed greater saphenous vein are a reasonable solution. Tibial veins should be ligated, do not waste time trying to repair them. They may also be divided to improve arterial exposure.

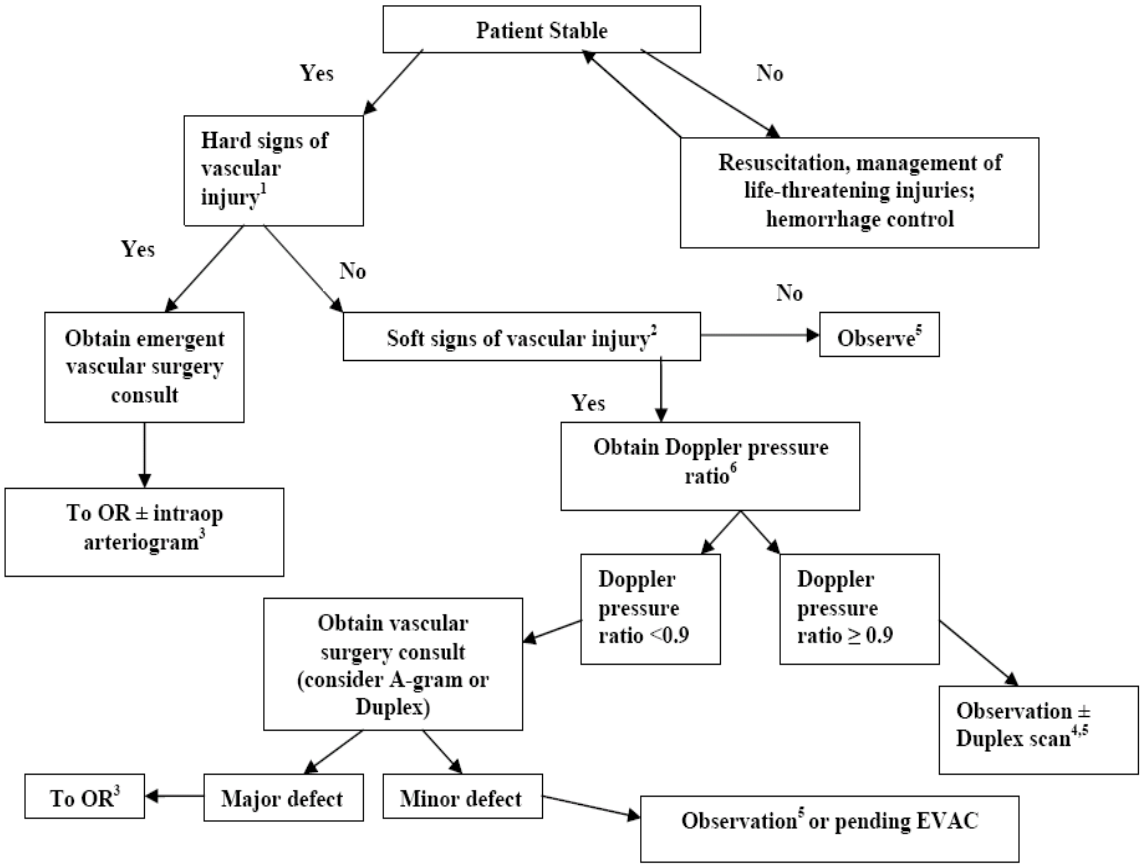
4. Responsibility. It is the responsibility of the trauma team leader to ensure his or her team is familiar with this CPG and the appropriate approach and repair of complex vascular injuries seen in combat trauma patients.

5. References.

[1] *Emergency War Surgery*

Approved by CENTCOM JTTS Director, JTS Director and Deputy Director and CENTCOM SG

APPENDIX A



1. Hard signs of vascular injury: expanding hematoma, bruit, thrill, active bleeding, severely ischemic extremity.
2. Soft signs of vascular injury: proximity of wound to major vessels, hx of hemorrhage/shock, non-expanding hematoma, diminished pulse and anatomically related nerve injury.
3. Prep contralateral saphenous vein in field, direct pressure (DP) to control bleeding (tourniquet only if DP fails).
4. Duplex scan when available.
5. Observe for evidence of compartment syndrome, change in vascular status. Ensure at least one follow-up vascular examination is performed.
6. Injured extremity to non-injured extremity systolic Doppler pressure ratio:
   - With the patient supine (for at least 10 minutes prior), take blood pressures (B/P) in both arms. Use the higher systolic pressure as the brachial pressure in the ratio.
   - Place the B/P cuff on the patient's leg just above the maleoli, and the Doppler probe at 45 degrees to the dorsal pedis or posterior tibial artery.
   - Inflate the cuff until the Doppler signal stops. Slowly deflate the cuff until the signal returns and record the numbers as the ankle systolic pressure.
   - To get the ABI ratio, divide the highest ankle pressure by the highest brachial pressure. For example, with systolic brachial pressures of 120 and 129 and an ankle systolic of 65, the ABI is 0.5. Perform on both right and left extremities. Farther from the heart, leg pressure is supposed to be higher than or at least equal to arm pressure. Interpret your ABI results based on these guidelines:

     0.9: Normal
     0.5 to 0.9: Claudication mild to moderate
     < 0.5: Resting ischemic pain, claudication
     < 0.2: Gangrenous extremity; suggests near total occlusion

APPENDIX B

Basic Principles

1. It is important to know the patient's total trauma burden and physiology when deciding how to manage their vascular injury.
2. Surgeons should become familiar with the key anatomical landmarks for several vascular exposures so they can be performed rapidly in the injured patient
3. Vascular trauma is the art of dealing with healthy arteries; it is similar, but different than dealing with vascular disease in the elderly.
4. Get proximal control outside of the hematoma / one level above the injury.
5. Once controlled, define the full extent of the vascular injury.
6. Gradually develop, and then optimize your work space so your hands are free to work.
7. Decide between complex vascular repair and damage control.
8. The safest place when dissecting out arteries is in the periadvential plane immediately next to the artery.
9. When performing vascular trauma systemic anticoagulation is not always possible if the patient has multisystem injuries. In these cases consider local heparinized saline infusion (1000 units heparin in 1000 cc of normal saline), proximally and distally.
10. Clear the inflow and outflow tracts before performing vascular repair or shunt insertion using an appropriately sized Fogarty balloon embolectomy catheter, generally #5 for large arteries and #3 for small ones.
11. DO NOT pass embolectomy catheters too much; you will be rewarded with intense vasospasm and worse outcomes.
12. Healthy traumatized arteries often exhibit intense vasospasm when manipulated; this may effect post-repair perfusion and can be relieved using local intra-arterial papaverine and nitroglycerin as the patient's overall condition allows.
13. Completion arteriography is not always possible. But some form of assessment is required such as improvement in pulse or Doppler examination; without this, be suspect.
14. Ligation is not an admission of defeat.
15. Transected aratery = interposition graft.
16. Vein repair is a luxury – not a must.
17. Use an intraluminal balloon for problematic distal control.
18. Bleeding and ischemia are different priorities.
19. Balloon tamponade controls external bleeding in transition zones.
20. Intra-arterial shunts are good damage control options in unstable patients; this can be accomplished using Rummel tourniquets and either internal shunts (Argyle) or external shunts (Javid).
21. External shunts that are placed entirely in the artery usually thrombose.

22. Sometimes, despite you doing everything right to improve perfusion to the extremity (including fasciotomies) the arm/leg still dies.